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Efficacy of carfentrazone, mesosulfuron + iodosulfuron and 2,4-D ester against *Rumex* spp. in wheat

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ABSTRACT

Rumex spp. is the major broad-leaf weed of irrigated wheat. Manual weeding is not feasible in wheat crop sown with a narrow spacing and weed management thus is accomplished through application of herbicides. The poor efficacy of otherwise effective herbicides so far against this weed has come to the fore indicating the likelihood of herbicide resistance. Hence, the present study was carried out during *Rabi* of 2017-18 at screen house of College of Agriculture, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana, India to evaluate herbicide resistance in *Rumex* spp. and its management in wheat crop using four test populations of *Rumex* spp. named as HHH (HAU Hisar), UPH (Ujha, Panipat), JHH (Jind), and JJR (Jhajjar). Three herbicides - carfentrazone, mesosulfuron + iodosulfuron and 2,4-D ester at three doses (0.5X, X and 2.0X) with one unsprayed control were taken as treatments in the pot experiment under completely randomised design (CRD) replicated thrice. Results indicated that all the populations have attained resistance against mesosulfuron + iodosulfuron even at double of the recommended dose. Higher values of plant height, chlorophyll fluorescence, dry weight and lower value of electrical conductivity was observed in mesosulfuron + iodosulfuron treated plants. Carfentrazone provided moderate control to all populations even at double of the recommended dose. The application of 2,4-D ester at double of the recommended doses provided 77-100% control of all populations except UPH where lower efficacy continued even at double dose. Resistance thus confirmed in *Rumex dentatus* requiring alternate herbicides for field level effective management.

Wheat *(Triticum aestivum* L.) is most important cereal crop and constitutes an integral component of food security system of several countries. At world level, it is grown in approximately 214 m ha area with production and productivity of 734 mt and 3425 kg/ha, respectively (FAO STAT, 2018). In India, it is the second most important food crop after rice with an annual production of 99.8 mt in an area of 30.6 mha with average productivity of 3220 kg/ha (Anonymous, 2018). Haryana is the major wheat growing state of India with an area of about 2.5 mha with 11.7 mt production and 4.6 t/ha productivity (Anonymous 2018).

Weeds cause significant losses in wheat productivity besides lowering down the quality of produce (Malik and Singh 1995, Singh *et al.* 1999) and also they have inhibitory effects on crop growth. Weeds causes yield losses of 15-50% in wheat crop (Jat *et al*. 2003, Singh *et al.* 1999). Extent of yield loss depends upon type and density of weed, soil characteristics and environmental conditions (Malik and Singh, 1995, Chhokar and Malik 2002). Weeds affect the crop yield by competing it with for light, nutrients, moisture and space (Singh and Singh 2005 and Singh 2007). In some cases, weeds may dominate to the extent of causing complete crop failure (Malik and Singh 1995, Singh *et al.* 1999). Weed stage, herbicide rates and fertilizers application impact weed control and crop-weed competition (Singh *et al.* 1995a, 1997). *Rumex dentatus*, *Chenopodium album*, *Medicago sativa*, *Melilotus alba* and *Fumaria parviflora* are major broad-leaf weeds in rice-wheat cropping system (Singh *et al.* 1995b, Chhokar *et al.* 2006). *R. dentatus* is a major broad-leaf weed of *Rabi* season and is a serious problem of irrigated wheat particularly in rice-wheat cropping system in North-Western Indo-Gangetic alluvial plains of India comprising of the state of Haryana (Singh *et al.* 1995b).

Poor efficacy of metsulfuron-methyl against the toothed dock (*Rumex dentatus* L.) was observed under field conditions and the subsequent studies confirmed the instances of herbicide resistance in this weed (Chhokar *et al.* 2013, Chhokar 2014, Heap 2014, Singh 2016 and Singh *et al.* 2017). In addition to metsulfuron herbicides like carfentrazone, mesosulfuron + iodosulfuron and 2,4-D ester have also been recommended for use in wheat crop for the control of broad-leaf weeds including the *Rumex* spp. It is worth to study the efficacy of these herbicides as well against this weed for possible resistance. There is a need to understand the level of resistance in different populations from rice-wheat belt of Indo-Gangetic plains against different broad-leaf weed herbicides. In addition, there is also a need to evaluate alternate herbicidal options for its management so that the problem of herbicide resistance may be tackled effectively by appreciating all attending factors in the production package of wheat crop including the likely phytotoxicity to wheat crop at higher doses.

Experimental details

A pot experiment was carried out in CRD (completely randomized design) replicated thrice using seeds of four populations of *Rumex dentatus* named as HHH (HAU Hisar), UPH (Ujha, Panipat), JHH (Jind), collected from putative resistance affected farmer's fields and an unidentified *Rumex*. sp from farmers field in Jhajjar district of Haryana JJR (Jhajjar). Seeds collected from research farm, CCSHAU, Hisar were used as standard check for comparison. Three treatments (mesosulfuron + iodosulfuron, 2,4-D ester and carfentrazone) were taken and applied at three doses (0.5X, X and 2.0X) to evaluate herbicide resistance in *Rumex* spp. and for its management.

Pot preparation

Soil was taken from Agronomy Research Farm area for filling the pots, which was free from seeds of *Rumex* spp. and not exposed to herbicides for the last two years. The soil was air-dried, well crushed in fine particles to pass through a sieve of 2 mm pore size. Plastic pots (63 diameter) were filled with 2 kg material comprising sand, vermi-compost and field soil in ratio of 2:3:1. Before sowing, the pots were properly watered in order to maintain optimum soil moisture and to exhaust the soil in the pots from weed seed bank. Populations of *Rumex* spp. were sown on 27th December, 2017. Fifteen seeds of *Rumex* spp. were sown in each pot at a depth of 3-4 cm. The pots were watered immediately after sowing. After the emergence, thinning was done and 10 plants/pot were maintained for the application of POE herbicides. The plants were sprayed at 38 DAS on 4th February, 2018. Herbicides were sprayed with a knapsack sprayer fitted with flat fan nozzle delivering 300 l/ha spray volume at 40 psi pressure. Unsprayed check was maintained for comparison of results. Harvesting was done on 26th April, 2018 at 120 DAS.

Observations recorded on *Rumex* spp.

Plant height: The plant height (cm) was measured from soil surface to the tip of the fully opened leaf at spraying time, 2 and 4 weeks after treatment (WAT).

Electrical conductivity (EC): The values of EC were taken at 4 WAT. At first, individual weed samples were placed in flasks containing distilled water for one day. After this, flasks containing samples were boiled to specific temperature enabling the salt of samples to dissolve in distilled water. Then EC reading was taken.

Chlorophyll fluorescence: The value of Chlorophyll fluorescence (Fv/Fm) were taken at 7 DAT (days after treatment) with the help of Hansatech chlorophyll fluorescence meter. In chlorophyll fluorescence meter, clips were used for dark adaptation. At first, these clips are fitted on leaves for twenty minutes period. Then these clips are hooked on chlorophyll fluorescence meter to record the chlorophyll fluorescence of the leaves, where the clips were initially fitted.

Per cent control: Per cent control of *Rumex* spp. was recorded at 4 WAT. Rating was done in 0-100 scale (0 means no control and 100 means complete control of *Rumex* spp.). This data was observed by comparing each treatment with unsprayed control.

Dry weight of weeds: The weed samples present in pots were harvested at 120 DAS and these samples were first dried under the sun light and then kept in oven at 65±5^{0}C till a constant weight was achieved. The dried samples were weighed and dry weight was expressed as g/pot.

Statistical analysis: All the observations were statistically analysed by using software OP STAT. Angular transformation also known as Arcsine transformation was used in per cent control data of weeds. Formula used for angular transformation was:

Arcsine transformation = ARSIN [SQRT(germination/100)]x90/1.571

Carfentrazone dose-response studies

The data pertaining the effect of carfentrazone on the plant height, electrical conductivity and per cent control at 4 weeks after treatments (WAT), chlorophyll fluorescence at 7 days after treatment (DAT) and dry weight at harvesting of various *Rumex* populations is presented in **Table 1**. As per the mean data over carfentrazone doses, significantly higher plant height (23.8 cm) and higher chlorophyll fluorescence (0.74 Fv/Fm) was observed in UPH followed by JHH, HHH and JJH, respectively. As per the mean data over *Rumex* populations, half dose of carfentrazone resulted in 14.2% higher plant height and 17.7% higher plant chlorophyll fluorescence over recommended dose, whereas double dose resulted in 9.1% lower plant height and 14.5% lower plant chlorophyll fluorescence than recommended dose. Significantly lower EC (ds/m) was observed in UPH (0.13), followed by JHH (0.19), HHH (0.22) and JJH (0.28) at 4 WAT.

As per the mean mortality data (%) recorded at 4 WAT over herbicide doses, significantly lower mortality (%) was recorded in UPH (30) followed by JHH (38), JJH (40) and HHH (65).The per cent mortality observed in JHH was found statistically at par with JJH. Half dose of carfentrazone resulted in 14.3% lower mortality in comparison to the recommended dose, whereas double dose resulted in 22.4% higher mortality than recommended dose. As per the mean data over carfentrazone doses recorded at harvesting (120 DAS), significantly higher dry weight (g/pot) was recorded in UPH (2.20) followed by JHH (1.73), JJH (1.43) and HHH (0.96). Significant differences were observed in herbicide doses with respect to dry weight. Half dose of carfentrazone resulted in 24.4% higher dry weight over recommended dose, whereas double dose resulted in 32.5% lower dry weight than recommended dose over all populations.

Rumex populations except HHH were not controlled by carfentrazone even at double of the recommended dose. It provided 58, 72 and 62% mortality in UPH, JHH and JJR, respectively at double of the recommended dose which may not be rated as satisfactory in actual field condition. Chhokar *et al.* 2011 and Shalu 2019 also reported moderate efficacy of carfentrazone against *Chenopodium* spp. These results vary from the findings of Chhokar *et al.* (2007) and same could be attributed to the development of resistance in above referred populations. Wherever herbicide efficacy has been achieved at double of the recommended dose, its extrapolation at field level intervention has to be correlated with the selectivity index of wheat crop with respect to that particular herbicide. The herbicide efficacy at double of the recommended dose would cease to be of significance if it proves phytotoxic to wheat crop. A reduction in Fv/Fm value was observed in carfentrazone treated plants and this result is in the line with the finding of Kumar *et al.* 2008.

Table 1. Plant height, chlorophyll fluorescence, electrical conductivity, mortality percentage and dry weight of *Rumex* populations as influenced by carfentrazone application.

Populations	Carfentrazone (g/ha)				
	0	7.2	14.4	28.8	Mean
Plant height (cm) at 4 WAT					
HHH	26.3	22.0	19.0	16.3	20.9
UPH	27.3	25.0	22.0	20.7	23.8
JHH	27.7	23.0	20.7	18.3	22.4
JJH	21.7	20.0	17.0	16.3	18.8
Mean	25.8	22.5	19.7	17.9	
		LSD (p=0.05)		SEm	
Population		0.9		0.32	
Herbicide		0.9		0.32	
Population x herbicide		NS		0.63	
Chlorophyll fluorescence (Fv/Fm) at 7 DAT					
HHH	0.85	0.70	0.51	0.35	0.60
UPH	0.91	0.77	0.69	0.61	0.74
JHH	0.91	0.72	0.64	0.55	0.70
JJH	0.84	0.70	0.67	0.62	0.71
Mean	0.88	0.73	0.62	0.53	
		LSD (p=0.05)		SEm	
Population		0.02		0.005	
Herbicide		0.02		0.005	
Population x herbicide		0.03		0.010	
Electrical conductivity (Ds/m) at 4 WAT					
HHH	0.02	0.28	0.37	0.46	0.8
UPH	0.03	0.09	0.15	0.26	0.13
JHH	0.03	0.13	0.20	0.39	0.19
JJH	0.03	0.25	0.28	0.31	0.22
Mean	0.03	0.19	0.25	0.36	
		LSD (p=0.05)		SEm	
Population		0.02		0.005	
Herbicide		0.02		0.005	
Population x herbicide		0.03		0.011	
Mortality percentage at 4 WAT					
HHH	0(0)	61(77)	69(87)	81(97)	53(65)
UPH	0(0)	30(25)	37(37)	50(58)	29(30)
JHH	0(0)	35(33)	43(47)	58(72)	34(38)
JJH	0(0)	41(43)	47(53)	52(62)	35(40)
Mean	0(0)	42(45)	49(56)	60(72)	
		LSD (p=0.05)		SEm	
Population		2		0.8	
Herbicide		2		0.8	
Population x herbicide		5		1.5	
Dry weight (g/pot) at harvesting					
HHH	2.47	0.70	0.53	0.13	0.96
UPH	3.23	2.30	1.97	1.30	2.20
JHH	2.83	1.80	1.37	0.93	1.73
JJH	2.40	1.33	1.07	0.93	1.43
Mean	2.73	1.53	1.23	0.83	
		LSD (p=0.05)		SEm	
Population		0.14		0.05	
Herbicide		0.14		0.05	
Population x herbicide		0.27		0.10	

Original figures in parentheses were subjected to angular transformation. WAT, weeks after treatment; DAT, days after treatment. DAS- days after sowing

Mesosulfuron + iodosulfuron dose-response studies

As per the mean data on plant height recorded over mesosulfuron + iodosulfuron doses at 4 WAT, significantly higher plant height (23.9 cm) was observed in UPH which was statistically at par with JHH (23.2 cm) but significantly higher than other populations (**Table 2**). Similarly higher chlorophyll fluorescence was observed in UPH and JHH, followed by JJH and HHH. Half dose of mesosulfuron + iodosulfuron resulted in 12.1% higher plant height and 6.88% higher plant chlorophyll fluorescence over recommended dose, whereas reverse trend was observed in case of double dose. The double dose resulted in 8.6% lower plant height and 6.8% lower plant chlorophyll fluorescence than recommended dose. Significantly lower EC (ds/m) was observed in UPH and JHH (0.06) followed by HHH (0.26) and JJH (0.20).

As recorded at 4 WAT, significantly lower mortality (%) was recorded in UPH (8) followed by JHH (18), JJH (53) and HHH (54). When compared the mortality achieved at recommended dose (X), the half dose of mesosulfuron + iodosulfuron resulted in 10% lower mortality, whereas double dose resulted in 17.5% higher mortality. When data was averaged over mesosulfuron + iodosulfuron doses, significantly higher dry weight (g/pot) was recorded in UPH (2.83) followed by JHH (2.27), HHH (1.18) and JJH (1.06). Mean dry weight in JJH was found statistically at par with HHH. No significant interaction was observed between herbicide doses and *Rumex* populations with respect to dry weight. Mesosulfuron + iodosulfuron 7.2 and 14.4 g/ha resulted statistically similar dry weight among all populations at harvesting (120 DAS). Half dose of mesosulfuron + iodosulfuron resulted in 9% higher dry weight over recommended dose, whereas double dose resulted in 12.9% lower dry weight than recommended dose over all populations.

All the *Rumex* populations showed unsatisfactory control even at double of the recommended dose of mesosulfuron + iodosulfuron. However, degree and extent of resistance showed variation across the populations. The highest dose (2X) provided only 17% and 28% mortality in UPH and JHH, respectively, whereas the corresponding figures for JJH and HHH was 82%. This may be due to resistance to mesosulfuron + iodosulfuron in UPH and JHH. Singh *et al.* (2016, 2017) and Bhullar *et al.* (2012) also observed the low efficacy of metsulfuron based herbicides against broad-leaf weeds of wheat. But these results vary with finding of Kaur *et al.* 2017 and Chhokar *et al.* 2007 that may be due to the development of resistance in the referred populations. UPH population attained higher plant height, chlorophyll fluorescence, fresh and dry weight and lowest EC which again is the manifestation of resistance behaviour in weeds. The results indicate that mesosulfuron + iodosulfuron may have to withdraw from the field level management practices recommended for *Rumex* though such advisory may be area specific.

Table 2. Plant height, chlorophyll fluorescence, electrical conductivity, mortality percentage and dry weight of *Rumex* populations as influenced by mesosulfuron + iodosulfuron application

Populations	Mesosulfuron + iodosulfuron (g/ha)				
	0	7.2	14.4	28.8	Mean
Plant height (cm) at 4 WAT					
HHH	26.3	20.0	18.7	17.0	20.5
UPH	27.3	25.7	22.3	20.3	23.9
JHH	27.7	24.7	21.7	18.7	23.2
JJH	21.7	18.3	16.3	16.3	18.2
Mean	25.8	22.2	19.8	18.1	
	LSD (p=0.05)			SEm	
Population	1.2			0.41	
Herbicide	1.2			0.41	
Population x herbicide	NS			0.81	
Chlorophyll fluorescence (Fv/Fm) at 7 DAT					
HHH	0.85	0.73	0.62	0.56	0.69
UPH	0.91	0.86	0.84	0.80	0.85
JHH	0.91	0.84	0.82	0.78	0.84
JJH	0.84	0.71	0.66	0.63	0.71
Mean	0.88	0.79	0.74	0.69	
	LSD (p=0.05)			SEm	
Population	0.02			0.005	
Herbicide	0.02			0.005	
Population x herbicide	0.03			0.01	
Electrical conductivity (Ds/m) at 4 WAT					
HHH	0.02	0.24	0.37	0.40	0.26
UPH	0.03	0.05	0.07	0.09	0.06
JHH	0.03	0.05	0.07	0.09	0.06
JJH	0.03	0.22	0.25	0.29	0.20
Mean	0.03	0.14	0.19	0.22	
	LSD (p=0.05)			SEm	
Population	0.02			0.005	
Herbicide	0.02			0.005	
Population x herbicide	0.03			0.010	
Mortality percentage at 4 WAT					
HHH	0(0)	54(65)	57(70)	65(82)	44(54)
UPH	0(0)	12(7)	18(10)	24(17)	14(8)
JHH	0(0)	27(20)	29(23)	32(28)	22(18)
JJH	0(0)	51(60)	57(70)	65(82)	43(53)
Mean	0(0)	36(38)	40(43)	47(52)	
	LSD (p=0.05)			SEm	
Population	3			1.1	
Herbicide	3			1.1	
Population x herbicide	6			2.2	
Dry weight (g/pot) at harvesting					
HHH	2.47	0.97	0.80	0.47	1.18
UPH	3.23	2.83	2.73	2.50	2.83
JHH	2.83	2.23	2.07	1.93	2.27
JJH	2.40	0.73	0.60	0.50	1.06
Mean	2.73	1.69	1.55	1.35	
	LSD (p=0.05)			SEm	
Population	0.14			0.05	
Herbicide	0.14			0.05	
Population x herbicide	0.29			0.10	

Original figures in parentheses were subjected to angular transformation. WAT, weeks after treatment; DAT, days after treatment.

2,4-D ester dose-response studies

When data was averaged over 2,4-D ester doses, highest plant height (cm) was recorded in UPH (22.8) which was statistically at par with JHH (22.1) but significantly higher than other populations (**Table 3**). Highest plant chlorophyll fluorescence (Fv/Fm) as recorded at 7 DAT was observed in UPH (0.72) followed by JHH (0.71), HHH (0.64) and JJH (0.61). Mean plant chlorophyll fluorescence of UPH was found statistically at par with JHH. When compared with recommended dose (X), half dose of 2,4-D ester resulted in 9% higher plant height and 10.2% higher plant chlorophyll fluorescence, whereas double dose resulted in 7.4% lower plant height and 6.8% lower plant chlorophyll fluorescence.Significantly lower EC (ds/m) was observed in UPH (0.29) followed by JHH (0.30) and JJH (0.33) and HHH (0.34).

In the mean data over herbicide doses as recorded at 4 WAT, significantly lower mortality (%) was observed in UPH (58) followed by JHH (61), HHH (69) and JJH (71).When compared with recommended dose (X), half dose of 2,4-D ester resulted in 18.1% lower mortality, whereas double dose resulted in 22.2% higher mortality. When data was averaged over 2,4-D ester doses, significantly higher dry weight (g/pot) was recorded in UPH (1.30) followed by JHH (1.18), JJH (0.87) and HHH (0.87). Half dose of 2,4-D ester resulted in 64% higher dry weight than recommended dose, whereas double dose resulted in 68% lower dry weight than recommended dose over all populations.

All populations were found sensitive to 2,4-D ester at recommended and 2X rate, though effect was lower on UPH population. Singh *et al.* (2017) and Chhokar *et al.* (2007 and 2017) also reported good efficacy of 2,4-D ester against broad-leaf weed of wheat, but these results are not in accordance with the findings of Chhokar *et al.* (2015) due to resistant behaviour of particular populations. The results indicate the efficacy of 2,4-D ester as the field level management practices for the resistant populations of *Rumex*. Reduction in chlorophyll fluorescence value was observed in 2,4-D ester treated plants and this is in the harmony with the finding of Singh and Singh (2006 and 2007).

It may be concluded that by knowing germination percentage of populations (highest in UPH population), seed formation of *Rumex* spp. can be arrested, which reduces the carry over weed infestation in the next season and it could be used as a tool in resistance management in this weed. Singh and Punia (2008) reported that *Rumex spinosus* was sensitive to flooding duration but not *R. dentatus*; whereas reverse was true for seeding depths. These agronomic practices including herbicide mixtures and sequential applications (Singh 2015) can be employed for the management of *Rumex* populations where possible. Majority of populations showed resistance against mesosulfuron + iodosulfuron even at double of the recommended dose. The resistance against the above mentioned herbicide was also reflected in terms of comparatively higher plant height, chlorophyll fluorescence and dry weight and lowest EC in the resistant populations, thus confirming the poor efficacy of mesosulfuron + iodosulfuron. All the populations except HHH showed poor efficacy against carfentrazone even at double of the recommended dose. *Rumex* populations on a whole

Table 3. Plant height, chlorophyll fluorescence, electrical conductivity, mortality percentage and dry weight of *Rumex* populations as influenced by 2,4-D ester application

Populations	2,4-D ester (g/ha)				
	0	7.2	14.4	28.8	Mean
Plant height (cm) at 4 WAT					
HHH	26.3	19.3	17.3	16.0	19.8
UPH	27.3	23.0	21.3	19.3	22.8
JHH	27.7	22.3	20.0	18.3	22.1
JJH	21.7	17.3	16.7	16.0	17.9
Mean	25.8	20.5	18.8	17.4	
	LSD (p=0.05)			SEm	
Population	0.8			0.28	
Herbicide	0.8			0.28	
Population x herbicide	1.6			0.56	
Chlorophyll fluorescence (Fv/Fm) at 7 DAT					
HHH	0.85	0.65	0.58	0.49	0.64
UPH	0.91	0.71	0.65	0.61	0.72
JHH	0.91	0.70	0.63	0.60	0.71
JJH	0.84	0.54	0.53	0.50	0.61
Mean	0.88	0.65	0.59	0.55	
	LSD (p=0.05)			SEm	
Population	0.02			0.007	
Herbicide	0.02			0.007	
Population x herbicide	0.04			0.013	
Electrical conductivity (Ds/m) at 4 WAT					
HHH	0.02	0.35	0.45	0.55	0.34
UPH	0.03	0.30	0.39	0.46	0.29
JHH	0.03	0.31	0.39	0.48	0.30
JJH	0.03	0.41	0.42	0.47	0.33
Mean	0.03	0.34	0.41	0.49	
	LSD (p=0.05)			SEm	
Population	0.01			0.004	
Herbicide	0.01			0.004	
Population x herbicide	0.02			0.007	
Mortality percentage at 4 WAT					
HHH	0(0)	67(85)	72(90)	89(100)	57(69)
UPH	0(0)	49(57)	61(77)	85(98)	49(58)
JHH	0(0)	52(62)	65(82)	89(100)	52(61)
JJH	0(0)	66(83)	89(100)	89(100)	61(71)
Mean	0(0)	59(72)	72(87)	88(100)	
	LSD (p=0.05)			SEm	
Population	2			0.82	
Herbicide	2			0.82	
Population x herbicide	5			1.6	
Dry weight (g/pot) at harvesting					
HHH	2.47	0.53	0.33	0.13	0.87
UPH	3.23	1.07	0.77	0.13	1.30
JHH	2.83	1.10	0.63	0.13	1.18
JJH	2.40	0.57	0.27	0.23	0.87
Mean	2.73	0.82	0.50	0.16	
	LSD (p=0.05)			SEm	
Population	0.12			0.04	
Herbicide	0.12			0.04	
Population x herbicide	0.24			0.08	

Original figures in parentheses were subjected to angular transformation. WAT, weeks after treatment; DAT, days after treatment were found sensitive to 2,4-D ester, as it provided significant visual mortality in case of all populations at recommended doses. The satisfactory control of 2,4-D ester to majority of populations provides an opportunity to integrate this herbicide in weed management options at field level.

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